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FISH SCHOOL TARGET STRENGTH AND DOPPLER MEASUREMENTS

by

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SOUTHWEST FISHERIES CENTER

July 1976

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NAVAL UNDERSEA CENTER, SAN DIEGO, CA. 92132

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Through a cooperative program with the National Marine Fisheries Service, a study of the acoustic characteristics of fish schools necessary to establish engineering parameters for the design of acoustic systems for the Navy was undertaken.

Target strengths of 10,534 fish schools in the California Current System (CCS) were measured. For pulse durations of 10 milliseconds, the average target strength was -7.3 decibels with a standard deviation of 5.3 and the average target strength for intensity was

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-2.4 decibels. Of all schools 73% ~~percent~~ had target strengths greater than or equal to -10 decibels; no values greater than 20 decibels were measured. Peak target strength was found to be both pulse length and range dependent.

Although the Doppler data were considered to be preliminary, 32% ~~percent~~ of the 260 schools examined displayed speeds greater than or equal to 1 knot. No ship avoidance by the schools was observed, and no speeds greater than 5 knots were recorded.

Schools size varied in extent from 5 to 250 meters, measured acoustically along the axis of the sound cone. The mean target extent was 64 meters with a standard deviation of 42 meters; a strong mode existed at 35 meters.

SUMMARY

PROBLEM

Through a cooperative program with the National Marine Fisheries Service, determine the acoustic characteristics of fish schools that are necessary to establish engineering parameters for the design of acoustic systems for the Navy.

RESULTS

1. Target strengths of 10,534 fish schools in the California Current System (CCS) were measured. For pulse durations of 10 milliseconds, the average target strength was −7.3 decibels with a standard deviation of 5.3 and the average target strength for intensity was −2.4 decibels. Of all schools, 73 percent had target strengths greater than or equal to −10 decibels; no values greater than 20 decibels were measured. Peak target strength was found to be both pulse length and range dependent.

2. The Doppler data gathered were considered to be preliminary; however, of 260 fish schools examined, 32 percent displayed speeds greater than or equal to 1 knot. No ship avoidance by the schools was observed, and no speeds greater than 5 knots were recorded.

3. School size varied in extent from 5 to 250 meters, measured acoustically along the axis of the sound cone. The mean target extent was 64 meters with a standard deviation of 42 meters; a strong mode existed at 35 meters.

RECOMMENDATIONS

1. Proceed with Doppler measurements in the CCS to establish a more refined data base.

2. Conduct detailed acoustic experiments on individual fish schools in the CCS to determine presently unknown but important parameters, such as packing density (compaction) and sound attenuation through schools.

3. Relate physical parameters, such as school size and compaction, to target strength.

4. Sample fish school target strengths and Doppler data in other geographic areas.

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INTRODUCTION

A cooperative acoustic program was initiated in 1974 between the Southwest Fisheries Center (SWFC) of the National Marine Fisheries Service and the Naval Undersea Center (NUC). SWFC was beginning a year of California Cooperative Fisheries Investigations (CalCOFI) (reference 1), and its research vessel, R/V DAVID STARR JORDAN, was to make six cruises over the CalCOFI grid from November 1974 through October 1975. Sonar mapping of fish schools (references 2 and 3) was a part of the measurements to be made during the cruises.*

Sonar data were collected on each cruise. Sampling efforts varied between cruises because of circumstances such as equipment failures. The cruise dates, sampling efforts, and results are summarized in table 1, and the portion of the CalCOFI station grid which was acoustically surveyed during the year is in figure 1.

PREVIOUS DATA COLLECTION

A description of the schooling pelagic fish stocks in the California Current System (CCS) is in reference 4. This reference contains descriptions of the results of combined acoustic-fishing surveys by the California Department of Fish and Game (CDFG) from northern California to the southern tip of Baja California over a span of seven years (1966 through 1973). Results provide overwhelming evidence that the northern anchovy, *Engraulis mordax*, is the dominant species in terms of biomass in the CCS.

The CDFG surveys combined acoustic search with midwater trawling to identify sonar targets. Of the many thousands of targets detected by both sonar and echo sounder, 80 percent were identified as anchovies. In 1384 midwater trawls taken during the surveys, anchovies were present in 70.8 percent of the catches. It is thus reasonable to assume that approximately 75 percent of the targets observed were schools of *E. mordax*.

EQUIPMENT

The R/V DAVID STARR JORDAN is equipped with a Simard Model 580-10 sonar system. The 30-kilohertz transducer is housed in a dome when not in use and lowered to a depth of approximately 4.5 meters when in operation. The transducer can be steered through 360 degrees in azimuth and from horizontal through 90 degrees to vertical in elevation. It projects a conical beam which is 10 degrees wide at the 3-decibel downpoints. The full-power optimum source level is 225 decibels referenced to 1 micropascal at 1 meter. The received signal is processed by amplification and bandpass filtering.

*The ultimate goal of the sonar mapping program is an assessment of local pelagic fish stocks.

Prior to each cruise, the transducer was calibrated dockside by hanging a test hydrophone* over the side at a distance of 7.5 meters from the transducer. Both source level and receiver sensitivity were calibrated in this manner.

Receiver sensitivity was measured through the transducer, receiver, analog-to-digital converter, and into the final data processing phases to ensure system component reliability and linearity. Calibrations obtained immediately prior to each cruise were those used for target strength computations on that cruise; variations between cruises were always less than 2 decibels.

Frequent system calibrations are important for two reasons: (1) the transducer is magnetostrictive and the insulation of the wire windings can deteriorate and (2) the final output stage of power amplification is supplied by vacuum tubes which can degrade with time. To check against the latter, the grid current was measured weekly while operating and the tubes were changed when the value fell below a certain standard.

In April 1975, a degradation in both source level and receiver sensitivity was noted during dockside calibration. The transducer was removed and rewound at NUC. After reinstallation, the operating characteristics returned to normal levels.

In addition to these checks, the vessel was taken to the Sensor Accuracy Check Site (SACS) facility (reference 5) in Long Beach, where independent measurements of source level and receiving sensitivity of the transducer with directivity patterns were obtained. This procedure was normally done once a year. The combined differences between the transducer source level and the receiving sensitivity measured at the SACS facility and at dockside were in all cases less than 3 decibels.

The main data processing instrument was a Digital Equipment Company PDP8I minicomputer which performed all data logging for fish school target strength and size features. A more sophisticated Hewlett Packard HP 2100 minicomputer system was obtained by NUC and programmed to gather and process fish school Doppler data for the May cruise.

METHODS OF MEASUREMENT

The standard SWFC survey is described in references 2 and 3; slight alterations were made during the May cruise to collect the Doppler data.

TARGET STRENGTH AND SIZE MEASUREMENTS (SHORT PULSE)

The transducer was trained 90 degrees to starboard and tilted 3 degrees down. A pulse duration of 10 milliseconds was used and the transmitter was pulsed once each second. Data were collected only between 0800 and 1600 hours and while the ship was

*Calibrated annually at NUC.

underway between stations at speeds greater than 7 knots. A sampling window with a range of 200 to 450 meters was used, i.e., no schools between the ship and 200 meters or with ranges greater than 450 meters were logged. This window was chosen to maximize the number of targets sampled and minimize the acoustic propagation anomalies. Schools possessing physical dimensions which overlapped the range window were excluded by the computer.

Prior to analog-to-digital conversion, the received signal was enveloped-detected and the PDP8I performed a sampling function over the digitized envelope at a rate of 750 samples per second, or one sample per meter of range. To distinguish schools from spurious targets, two procedures were followed. For each pulse, the signal amplitude for a target had to be higher than a predetermined threshold (slightly higher than background) and this amplitude had to continue over at least five consecutive samples. This in effect limited the smallest school sampled to 5 meters. The target also had to be present over at least three consecutive pulses, which minimized the processing of noise spikes since they seldom correlate over this length of time.

Data from three consecutive pulses were stored in the computer, and as each new data set entered it was tested for the presence of targets. When a target was present, the amplitudes of consecutive samples were compared and the peak values stored. Peak target strength, midrange values, target extent, and number of pulses containing the target were then computed and stored in memory along with time of day and ship speed. The peak target strength was computed from

$$TS = 10 \log (p/p_o)^2 + 40 \log R + 2 \alpha R \qquad (1)$$

where TS is the target strength; p is the peak backscattered pressure received at the transducer; p_o is transmitted pressure; R is the midrange value of the target; and α is the attenuation coefficient (5.5 decibels per kilometer was used for 30 kilohertz). Spherical spreading and a sound speed of 1500 meters per second were assumed. Downward refraction is the dominant feature in the CCS and transmission anomalies for these short ranges are negligible. An arbitrary lower limit of −20 decibels was selected for target strength in this report and, in fact, less than 1 percent of the targets had strengths smaller than this value.

At 1600 hours each day, memory-stored results of the previous 8 hours were printed-out on a teletype terminal and simultaneously punched on paper tape. The paper punch tape data were then edited and transferred to digital magnetic tape for storage and final analysis on the HP 2100 system.

DOPPLER MEASUREMENTS (LONG PULSE)

During the May cruise, the NUC HP 2100 system was used in addition to the PDP8I to obtain preliminary Doppler measurements of fish schools. This necessitated some procedural changes: (1) the sampling window was enlarged to encompass an area of 200 to 600 meters and (2) pulse transmission, both duration and sequence, and carrier frequency were controlled by the HP 2100. The pulse sequence was 14 short pulses (10 milliseconds)

followed 1 second later by a long pulse (170 milliseconds); a 2-second delay; and repeat. For frequency accuracy, the 30-kilohertz carrier was generated by a crystal oscillator accurate to ±0.002 percent (±0.6 Hertz). The PDP8I analyzed the short pulse data as before.

Frequency spectrum (Doppler) data were processed in real time aboard ship as follows. The received signals from the 170-millisecond pulses were processed by amplification and bandpass filtering. The signal was then multiplied by a 29.5-kilohertz signal (also crystal generated with the same accuracy as the 30-kilohertz crystal) and the sum frequency was filtered off, a process which left a 500-Hertz narrowband signal for analysis. This signal was digitized in the computer and examined for the presence of targets. To be considered a target the signal had to have a target strength greater than –20 decibels and maintain that level for a time greater than one-quarter the pulse duration, or 0.042 second.

For those returns classified as targets, a fast Fourier transform (FFT) was performed in the computer. The sampling rate of the computer was 2048 points per second, ca 4 samples per cycle, and the maximum number of points possible for the FFT was 1024, ca 500 milliseconds. Only those points associated with the target were used by the FFT; the remainder was set to zero. The absolute radial speed of a target was referenced to background volume reverberation at a range just prior to the target.

RESULTS AND DISCUSSION

DOPPLER DATA

Doppler measurements obtained during cruise 94 are in figure 2. Positive velocities indicate motion toward the ship. The mean velocity was zero with a standard deviation of 1.2 knots. No net motion either toward or from the vessel is indicated by these preliminary data. Figure 3 presents the same data as a cumulative distribution of percentages of speed greater than or equal to a particular speed, e.g., 32 percent of the 260 targets sampled had measured speeds in excess of 1 knot.

Certain constraints were imposed upon the Doppler experiment because of the standard survey technique used. With the transducer trained to 90 degrees, only the velocity component normal to the ship's track could be measured. Also the combination of forward motion of the ship and finite horizontal beamwidth (±5 degrees) of the transducer could produce an apparent Doppler component, although the target had no real motion relative to the water mass. A stationary target located in the horizontal plane containing the acoustic axis but at either edge of the beam would have an apparent motion of V_0 sin 5 degrees, where V_0 is the speed of the vessel. For a ship speed of 10 knots, the apparent Doppler would be ±0.9 knot. Thus the data presented here contain an ambiguity which ranges from zero for those targets acquired on the acoustic axis to approximately ±1 knot for those at the 3-decibel downpoints.

For these reasons, the Doppler data are considered as preliminary. However, certain objectives were met: a reasonable estimate of the higher swimming speeds reached by fish schools in the CCS and an indication that there appears to be no avoidance or attraction to the vessel by fish schools at the ranges used for the experiment.

The sonar aboard the R/V DAVID STARR JORDAN was also used to make Doppler measurements, discussed in reference 6, of three fish schools in the CCS. The principal reasons for this experiment were to measure frequency spectrum changes internal to the schools and to relate these data, by using relationships between tail-beat frequency and fish length, to the average size of individual fish in the school. During these experiments the ship drifted; the 11-kilohertz sonar tracked the schools and measured school velocity changes relative to the ship; and the 30-kilohertz sonar collected the frequency data of the fish schools and the surrounding water mass. For the three schools, the mean cruising speeds were 0.9 meter per second (1.9 knots), 0.85 meter per second (1.6 knots), and 0.45 meter per second (0.9 knot), values which are in reasonable agreement with the results in this report.

TARGET DIMENSION

Sizes and shapes of fish schools are extremely varied, complex, and difficult to measure. An excellent example of such data is the work of Voglis and Cook (reference 7) who used high-resolution sector scanning techniques to observe fish schools. School shapes observed on the display are included in their report and vary from small ellipses to plumes. Figure 4 shows shapes in the CCS for both day and night aerial observations.

During the CalCOFI survey, target extent data, as well as information on size and shape, were collected. Target extent is defined as the dimension of the target parallel to the acoustic axis of the transducer. For each school encountered, it was determined from the returned echo length corrected for pulse length. In figure 5, target extent is plotted in 10-meter intervals as a function of relative frequency of occurrence. The mode for this distribution is 35 meters. The mean target extent is 64 meters with a standard deviation of 42 meters. Thus the most frequently observed value for target extent was 35 meters; however, half the schools had a value greater than or equal to 64 meters.

Several possible forms of sampling bias exist concerning target extent data: (1) smaller targets normally possess lower target strengths and therefore may fall below the detection threshold at the farthest ranges inside the window and (2) targets which overlap the edges of the window's range are discarded, thereby causing undersampling of larger targets. Figure 6 shows the bias of the sampling window. Here the sampling window is divided into 1-decibel steps of (10 log) volume:

$$10 \log \text{volume} = 10 \log (\pi R^2 \tan^2 \theta \; c \, \tau/2) \qquad (2)$$

where R is the midrange value of the range increment, θ is 5 degrees, c is 1500 meters per second, and τ is a pulse duration of 0.01 second. Values for the mean target strength, standard deviation, and mode are also superimposed in figure 6. For example, 23 percent of the schools were in the range increment of 315 to 355 meters and the sonar sampled 43 decibels of volume at the midrange value of this increment (335 meters); the mean target strength for the increment was –5.8 decibels with a standard deviation of 4.8 decibels; and the most frequently observed target strength was –6 decibels. This figure also shows the dependence of peak target strength on sampling volume (range).

Other measurements of target extent are in references 2, 3, and 4. In reference 2, Smith used a pulse duration of 1 millisecond and the target selection criterion that received amplitude had to continue only over two consecutive samples, compared to the five samples used in this report. The mode of distribution occurred within the 10- to 15-meter interval. Measurements from a preCalCOFI cruise, obtained using the identical selection criteria as in this report, for a small geographic area and time sample are in reference 3. The mode of distribution, after correction for pulse length ($c\tau/2$), occurred within the 21- to 30-meter interval. Mais in reference 4 presents school diameter distribution data as measured acoustically; the mode fell in the 31- to 40-meter interval. Based on these independent results, it seems reasonable to conclude that the most likely value for target extent for fish schools should be between 20 and 40 meters.

The Mais data also showed that for all four seasons 75 percent or more of all schools were less than 40 meters in diameter (90 percent in the spring). Mais used echo sounders in conjunction with the horizontal-looking sonar to measure the schools' vertical thicknesses, which ranged from 4 to 65 meters with a mean of approximately 12 meters. However, he feels that these values are biased because some schools, especially the shallower ones, avoided the ship.

TARGET STRENGTH

Histograms of the target strength data for the R/V DAVID STARR JORDAN cruises are in figure 7 (a through g). Included are statistical determinations made on each data set, i.e., the mean target strength in decibels ($\overline{TS}$ (dB)), standard deviation, mean intensity target strength in decibels ($\overline{TS}$ (I)), and number (N) sampled. The different mean target strengths are defined as follows:

$$\overline{TS}\,(\mathrm{dB}) = 1/N \sum_{i=1}^{N} TS_i \; ; \tag{3}$$

consider TS = 10 log I where I is the ratio of scattered intensity at 1 meter to incident intensity; and

$$\overline{TS}\,(I) = 10 \log 1/N \sum_{i=1}^{N} I_i \, . \tag{4}$$

This distinction has been included in this report because $\overline{TS}$ (dB) represents the mean of the data displayed in the histogram and $\overline{TS}$ (I) represents the mean intensity as measured by the receiver.

Figure 8 shows the cumulative distributions of the percentages of target strengths greater than or equal to a particular value of target strength, e.g., 73 percent of the 10,534 schools had target strengths greater than −10 decibels (figure 8b).

Measurements of target strength computed for the long pulse data (170 milliseconds) are in figure 9. Comparison of these data with the histogram of short pulse data from the same cruise (figure 7d) indicates that the measurements of the peak target strength of fish schools are pulse length dependent. The difference in average intensity ($\overline{TS}$ (I)) is 8.7 decibels, but the difference in the 10 log pulse length is 12.3 decibels.

Many studies of the target strengths of individual fish have been reported in the last decade (see reference 8 for a review), but measurements of the target strengths of schools have been made only in a few isolated instances (references 9 and 10). Some preCalCOFI data, collected and analyzed by NMFS and NUC, are reported in reference 3, but the largest reported set of data is that in reference 11. These data were also taken from the R/V DAVID STARR JORDAN, using the same sonar and transducer, but with different personnel and signal processing equipment and a shorter pulse duration (1 millisecond). They were measured in the same geographical area. Figure 10 shows the cumulative distribution of percentages of targets with strengths greater than or equal to a particular target strength for the two data sets. For the NUC data, $\overline{TS}$ (dB) = –7.3 decibels and $\overline{TS}$ (I) = –2.4 decibels; for the Tracor data, $\overline{TS}$ (dB) = +12.8 decibels and $\overline{TS}$ (I) = +18.3 decibels. The differences between the two sets are 20.1 decibels for $\overline{TS}$ (dB) and 20.7 decibels for $\overline{TS}$ (I); there is no explanation to date for these differences. (The sample size for the Tracor data was 209 schools.)

Comparisons between cruises (figure 7 and table 1) suggest that seasonal variations in target strength exist. These could be caused by several factors: (1) different acoustic propagation conditions between seasons; (2) different behavioral characteristics of the individuals in the schools; (3) different sizes or size mixtures comprising the schools; (4) different school compactions; and (5) bias caused by unequal sampling effort, particularly valid for the last cruise. An example of seasonal variation is suggested in the unique bimodal distribution evident in figures 7d and 7e, which may be caused by the emergence of the new year class of anchovy.* Another interesting observation is that there were less targets per sampling hour for the June-July cruise (number 95) as compared to the other cruises. Average intensity ($\overline{TS}$ (I)), however, was the highest for this cruise, which suggests that the schools may have been fewer in number but larger and more compact than during other seasons.

Target extent as a function of range is in figure 11. The horizontal axis, extending from 200 to 450 meters, is in 25-meter intervals. The vertical axis, in 10-meter intervals, is the average target extent. For a given 25-meter range interval the points with standard deviation bars indicate the average target extent and dispersion of targets whose midrange values occur within that interval. The symbol (x) refers to the mode of the distribution occurring within each interval. The horizontal full angle of the sonar is 10 degrees; therefore, the length subtended is 2R tan 5 degrees. The bias inherent in the sampling method is obvious at either end of the window. If the schools were considered to be horizontally symmetrical, the figure would indicate that some of them were beamlimited. The fact that schools occur in complex horizontal shapes (figure 4), however, obscures the number of schools which was affected.

*Personnel communication, Dr. P. Smith, SWFC.

Figure 12 shows the average peak target strength as a function of target extent in 10-meter intervals. For a given interval, the points with the standard deviation bars superimposed provide the $\overline{TS}$ (dB) and the range of the target strength; the symbol (x) indicates $\overline{TS}$ (I). For example, for targets with a target extent between 101 and 110 meters, $\overline{TS}$ (dB) is -5.6 decibels and $\overline{TS}$ (I) is -3 decibels. The figure indicates that the dependence of the peak target strength on target extent is not strong, but, in general, the larger the target extent, the higher the target strength. The dependence, however, may be obscured by the irregularity of the school shapes and the resultant beamlimiting problem previously discussed.

A comparison of average target extent and peak target strength is in figure 13. For example, for targets with $-19 \leqslant TS < -17$, the average target extent is 28 meters (•) with a standard deviation of 20.5 meters; the most frequently observed target extent (x) is 15 meters; and the number above the standard deviation bar signifies that 3.22 percent of the 10,534 targets occurred within this target strength interval. The dependence of average target extent from -20 to 0 decibels is quite noticeable and nearly linear. Note that $\overline{TS}$ (dB) of -7 decibels (figure 7g), the average target strength of all 10,534 targets, corresponds closely to the average target extent of 64 meters (figure 5). Above 0 decibel, the target extent appears to be independent of the target strength; however, less than 7 percent of the targets possessed values for target strength greater than 0 decibel. Thus the size of the data set above 0 decibel may be too small to provide an accurate indication of any trend. In addition, targets possessing values for target extent greater than 80 meters may be beamlimited.

COMMENTS

The interaction between acoustic energy and a fish school is a complex phenomenon. An attempt to describe satisfactorily that interaction in a numerical and quantitative manner is an ambitious undertaking. From the point of view of fisheries research, the most desirable model would be one which could be used to extract certain biological and physical properties and parameters from the acoustic information (reference 3). For Navy design purposes, the acoustic measurements themselves may be sufficient.

Several authors, however, have presented treatments of this particular problem and Weston's (reference 12) appears to be the most applicable. Weston proposes that for a school of fish the response is composed of the sum of coherent and incoherent components. The coherent term represents the return from the school as a local change in compressibility of the medium. The incoherent term results from considering the school as an array of scatterers. These components depend upon certain properties of the school: (1) size, shape, and "roughness" of the school; (2) compaction (fish per cubic meter); (3) multiple scattering within the school; (4) target strength of individual fishes; (5) attenuation; and (6) orientation. In addition, he postulates that at high frequencies a school may reflect very little acoustic energy, but will absorb virtually all incident acoustic energy.

While the present data set provides information of the range of values for target strength, target extent, and range (volume) dependence, the values of parameters, such as individual target strength, compaction, and attenuation, that are necessary for model prediction are not presently known with sufficient accuracy to generate a meaningful contribution.

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Table 1. Dates and results for six CalCOFI cruises.

Cruise Number	Date Start	Date End	Number of Schools	Sample Time, hr	TS (dB), dB*	Standard Deviation, dB	TS (I), dB**
Short Pulse Data (10 msec)							
90	26 Nov 1974	20 Dec 1974	2,407	100	−7.2	4.9	−4.5
91	20 Jan 1975	8 Feb 1975	2,819	120	−5.6	5.5	−0.9
92	28 Feb 1975	26 Mar 1975	1,848	102	−8.4	5.3	−4.4
94	8 May 1975	4 Jun 1975	2,004	90	−8.3	5.9	−3.9
95	26 Jun 1975	20 Jul 1975	826	82	−5.6	8.2	+2.0
98	19 Oct 1975	29 Oct 1975	630	30	−10.9	6.0	−6.1
Total			10,534	524	−7.3	5.9	−2.4
Long Pulse Data (170 msec)							
94	8 May 1975	4 Jun 1975	260		+1.6	5.6	+4.8

*Mean target strength
**Target strength related to mean intensity measured at receiver

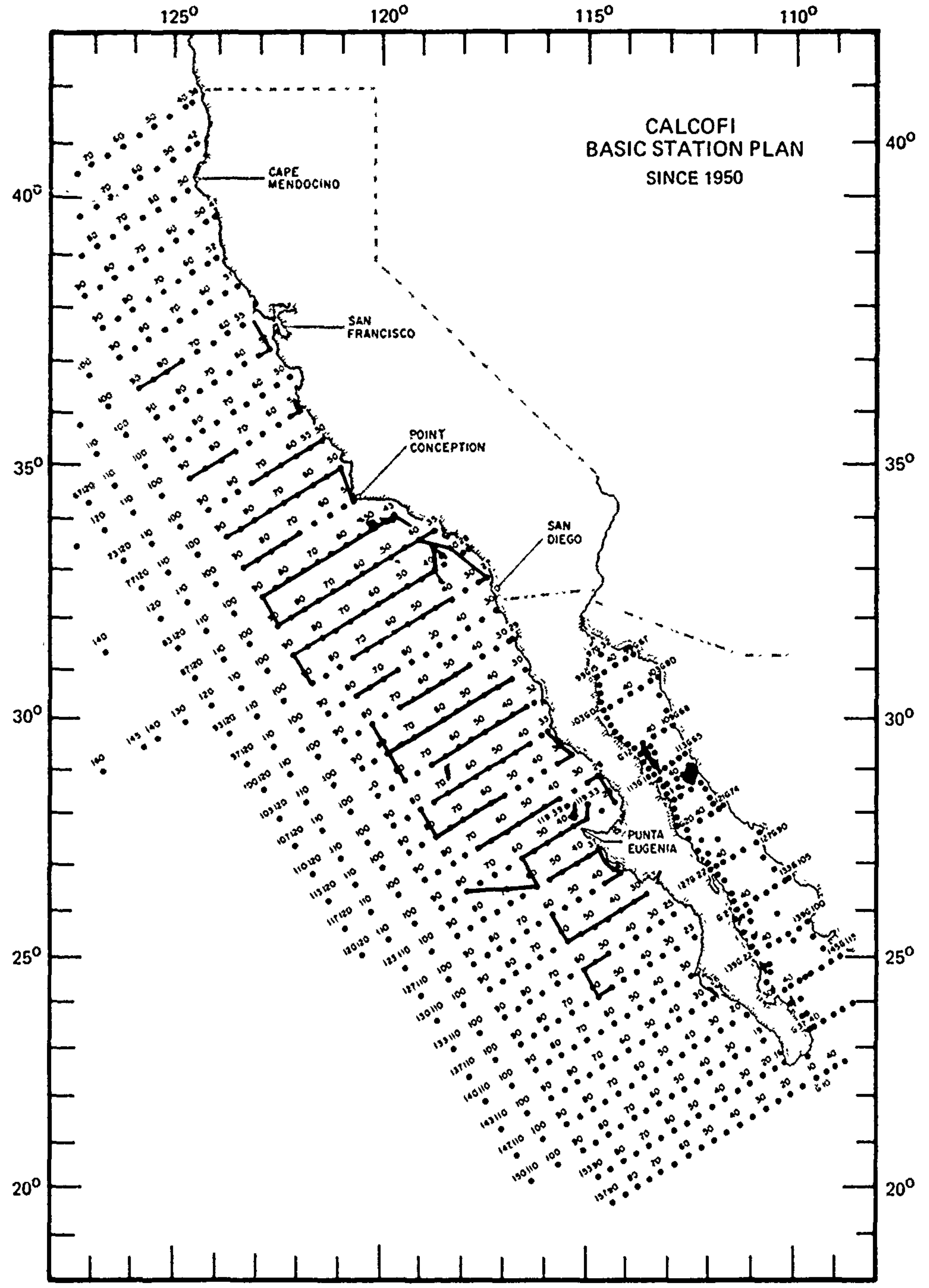


Figure 1. Basic CalCOFI station grid; lines represent transects surveyed acoustically during the CalCOFI year of cruises.

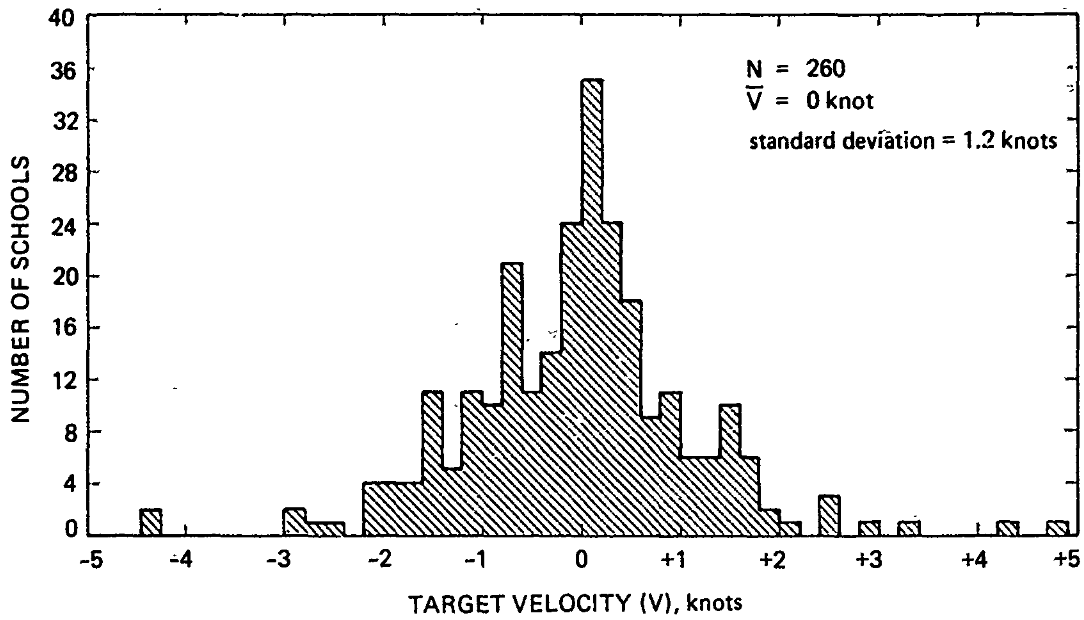


Figure 2. Doppler measurements from cruise 94. Positive Doppler indicates motion toward ship.

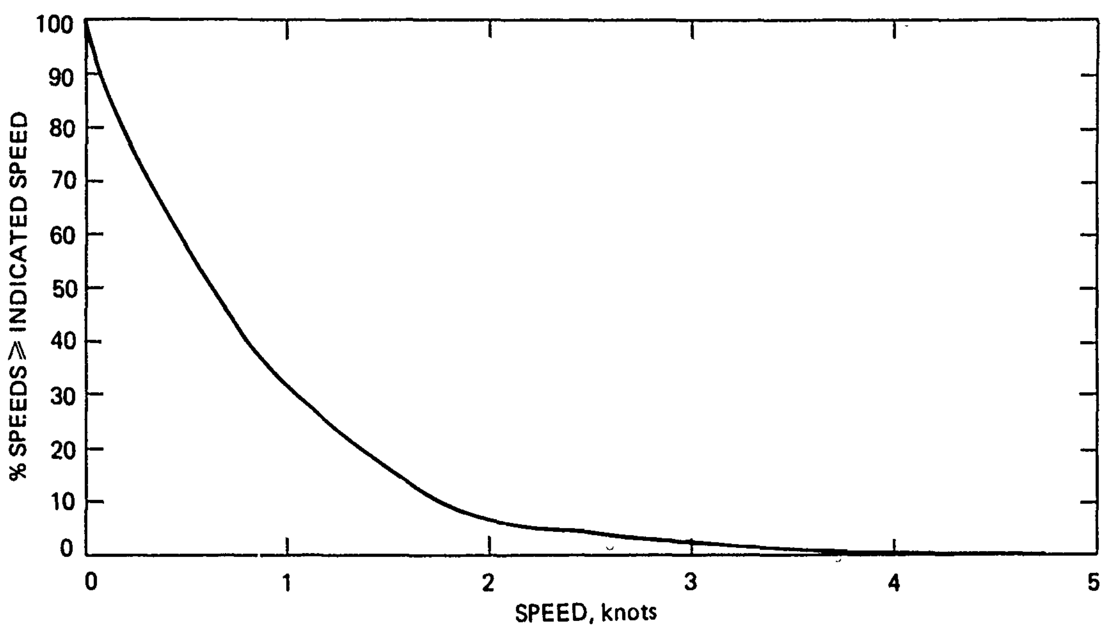


Figure 3. Cumulative distribution of percentages of school speeds greater than or equal to a particular speed. (Based on data from figure 2.)

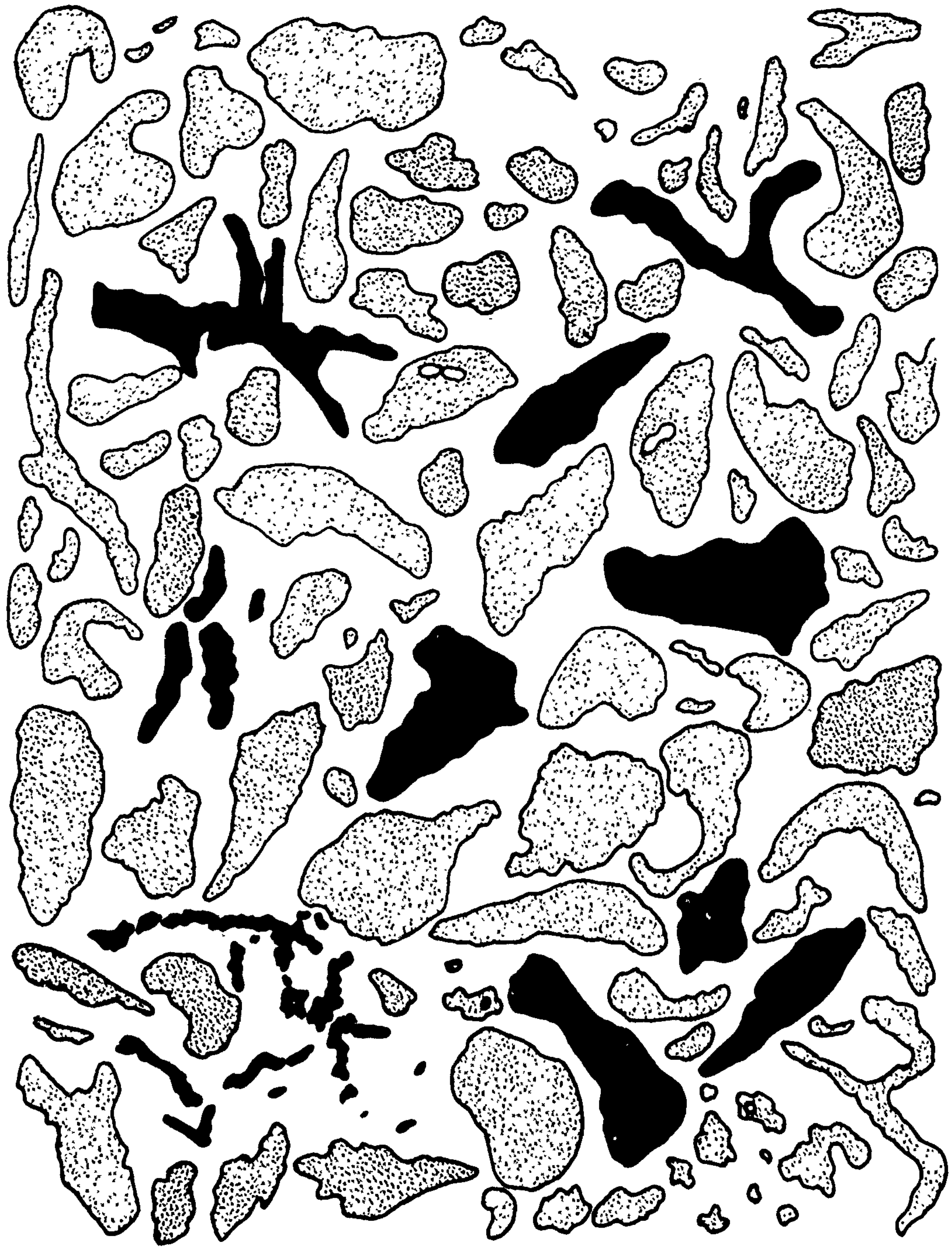


Figure 4. Shapes exhibited by fish schools in the California Current (taken from aerial photographs). Black schools were photographed at night with a low-light intensity amplifier. Horizontal size of the schools is relative. (Figure courtesy of J. Squires, SWFC.)

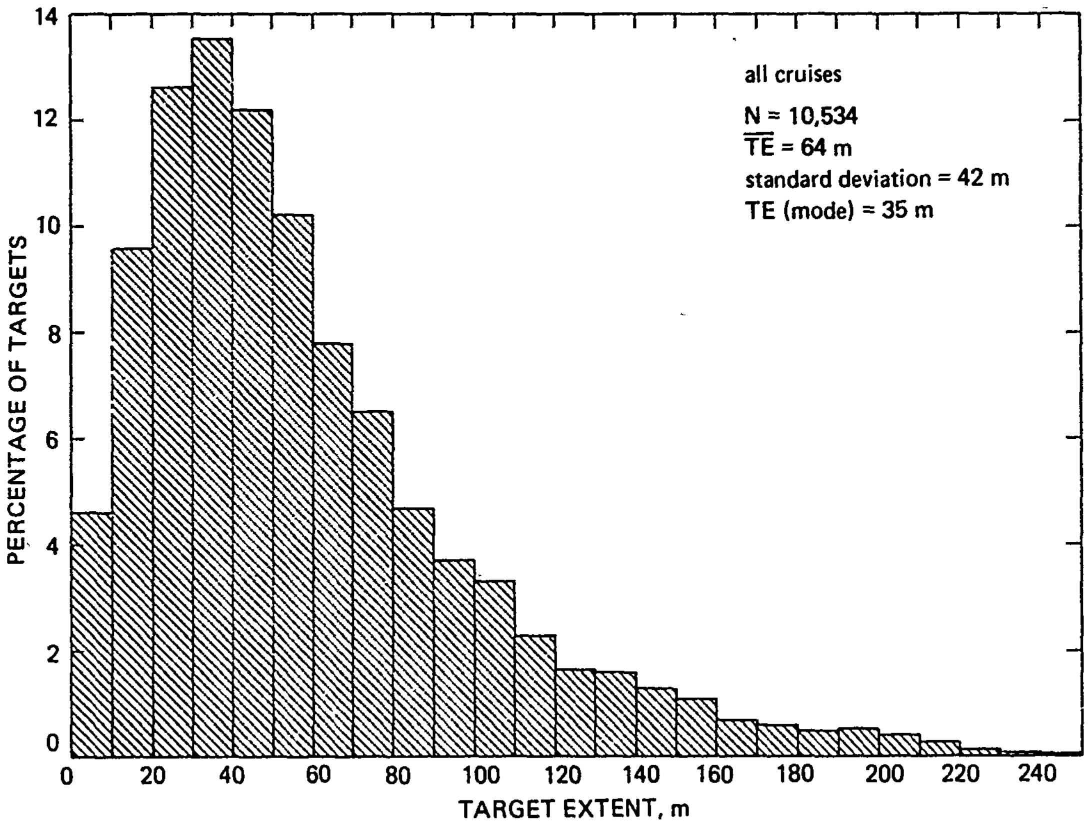


Figure 5. Target extent as a function of frequency of occurrence.

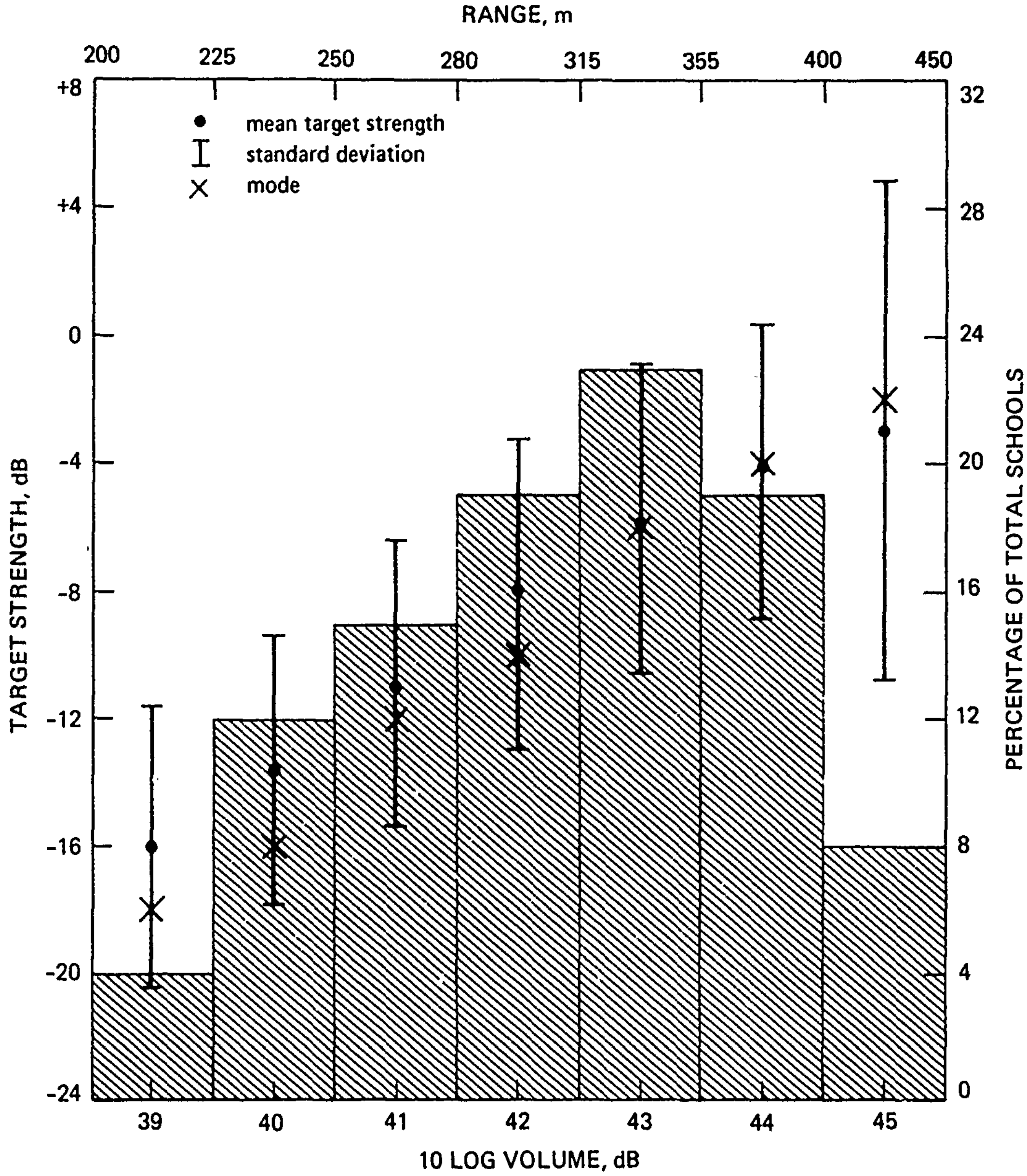
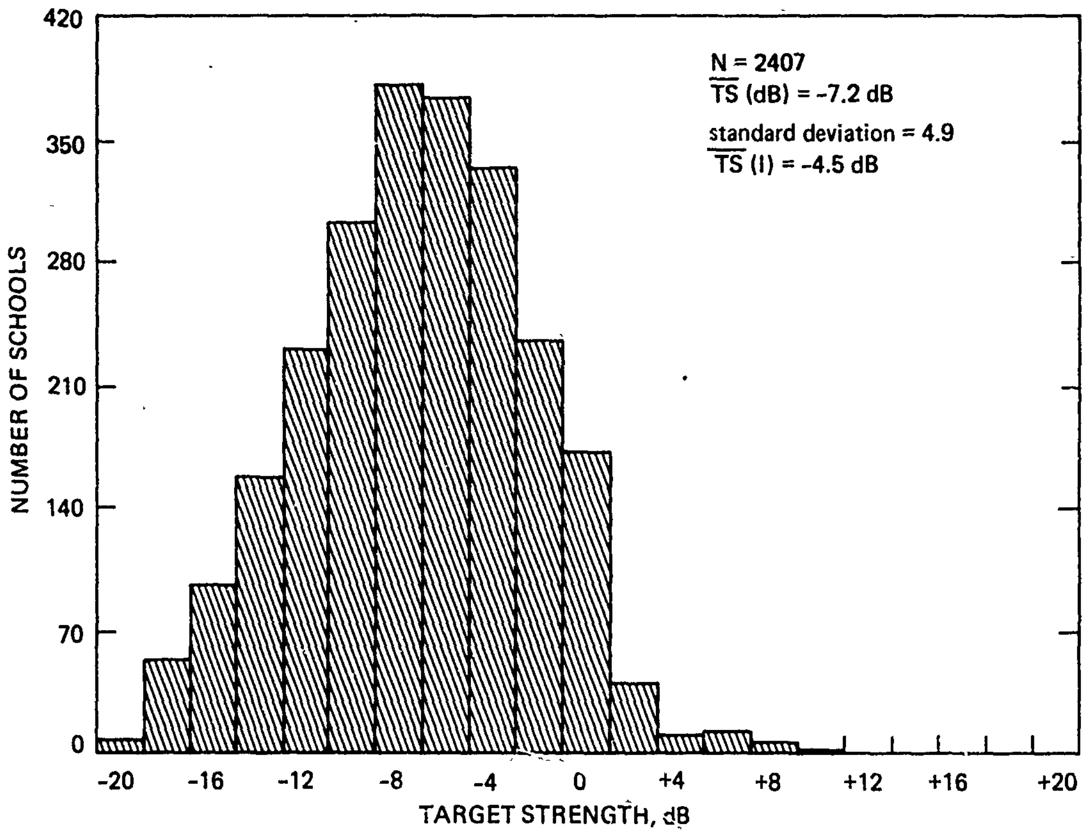
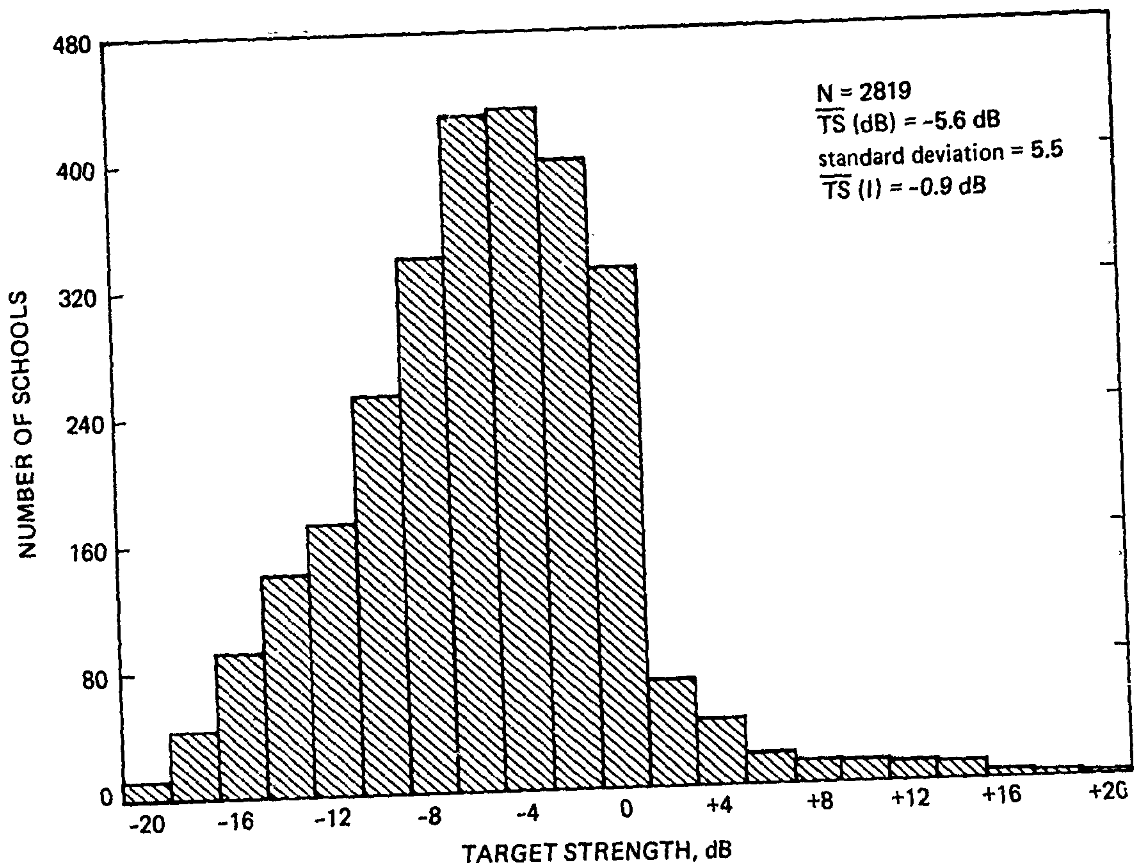


Figure 6. Sampling window divided into 1-decibel steps of (10 log) volume. Range increments for the 1-decibel steps, shown at the top, are not linear. Percentages of the total number of schools in each step are shown in the histogram. Mean target strength, standard deviation, and most observed target strength (mode) are superimposed.



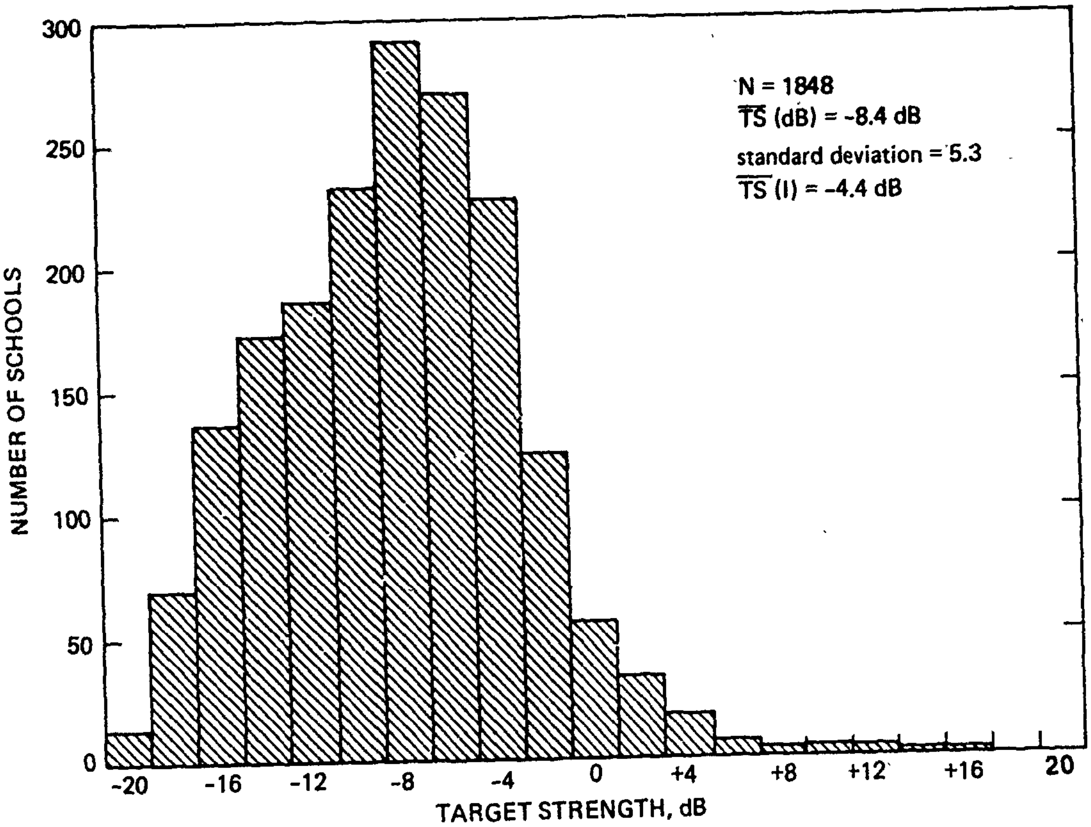
Part A. Cruise 90, 26 November through 20 December 1974.

Figure 7. Target strength as a function of frequency of occurrence for short pulse data (10 milliseconds).



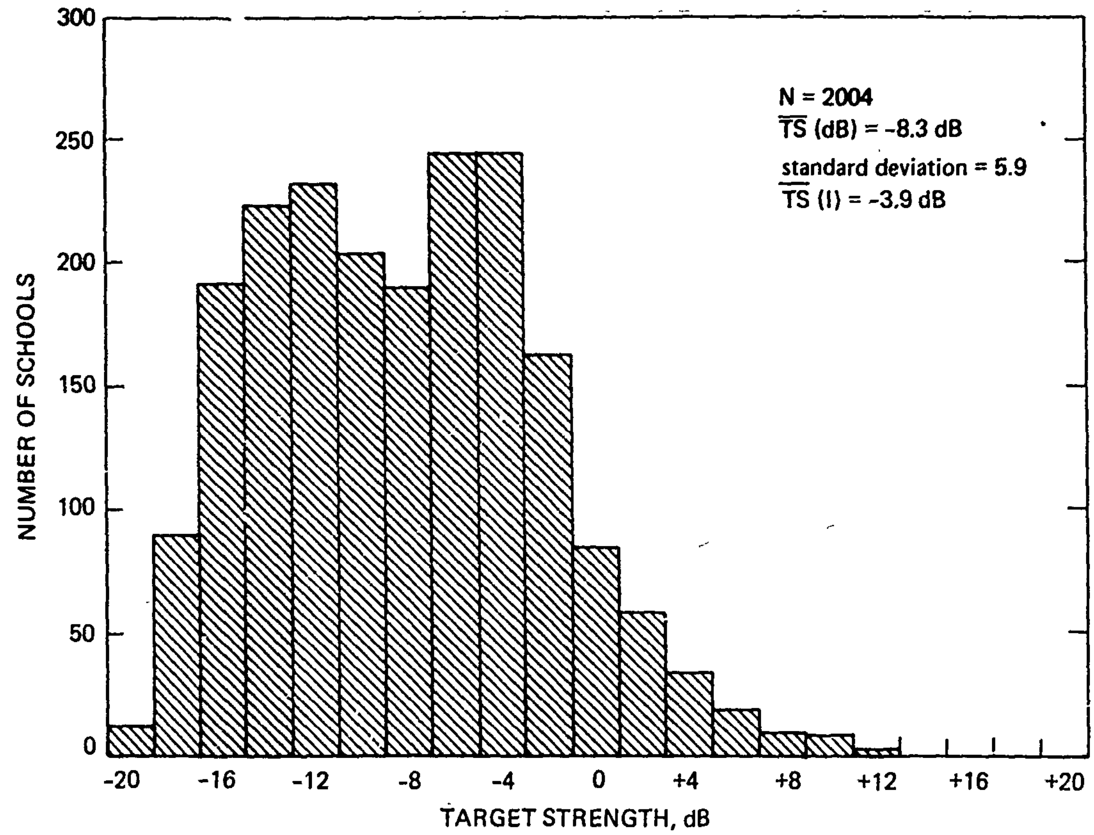
Part B. Cruise 91, 20 January through 8 February 1975.

Figure 7. Continued.



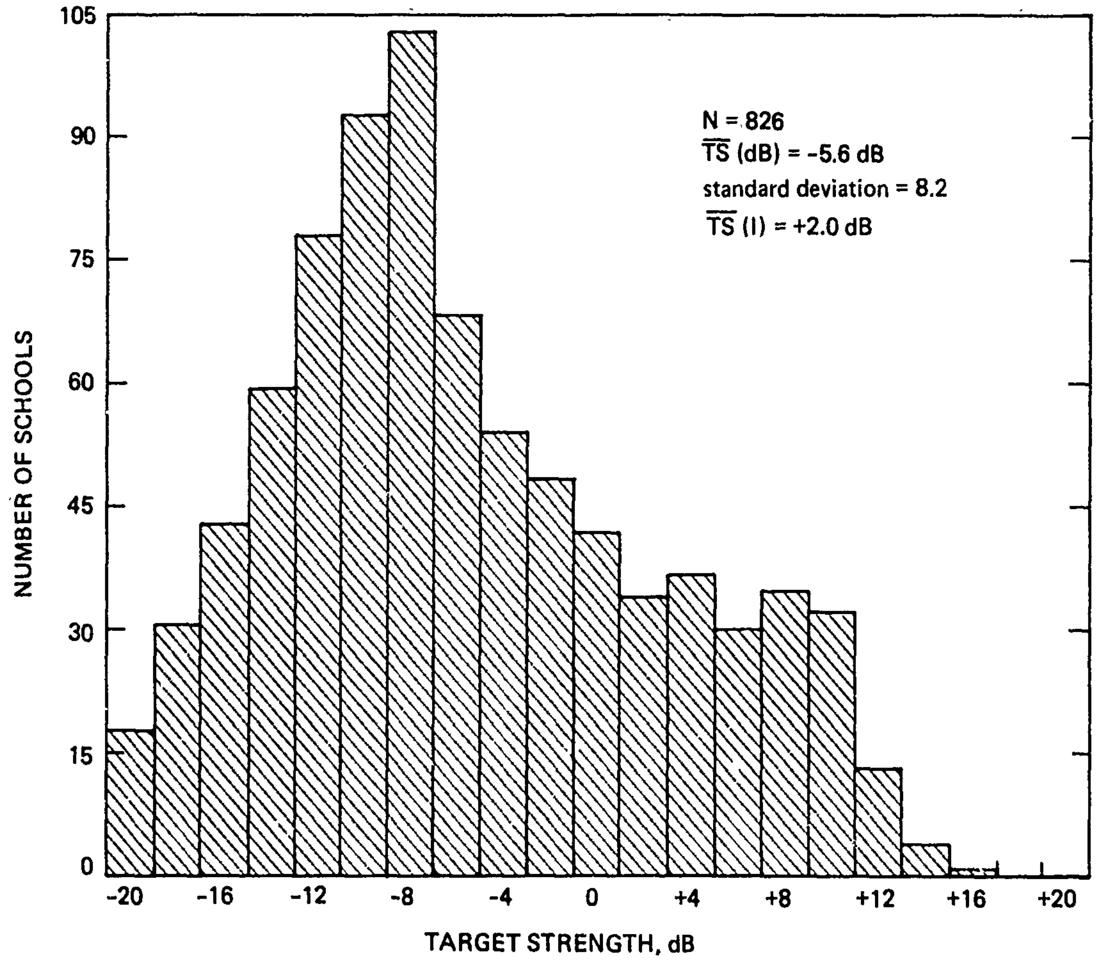
Part C. Cruise 92, 28 February through 26 March 1975.

Figure 7. Continued.



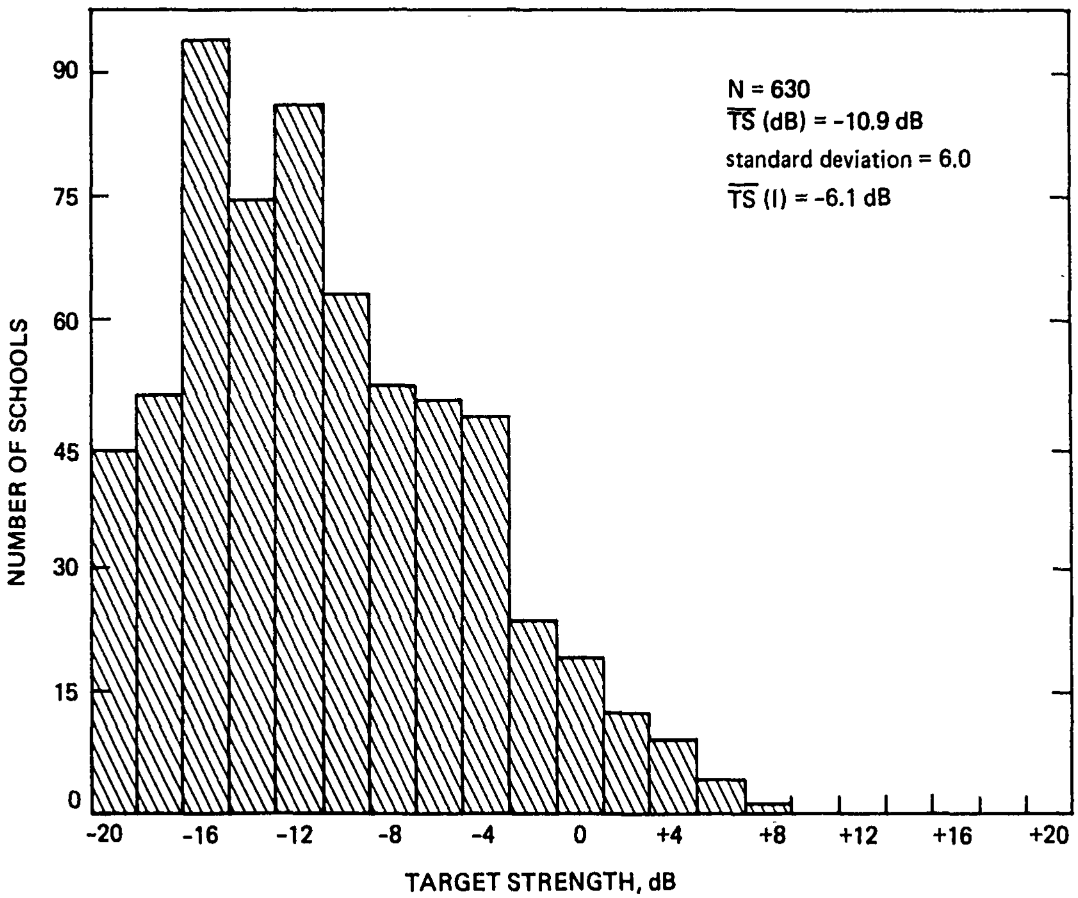
Part D. Cruise 94, 8 May through 4 June 1975.

Figure 7. Continued.



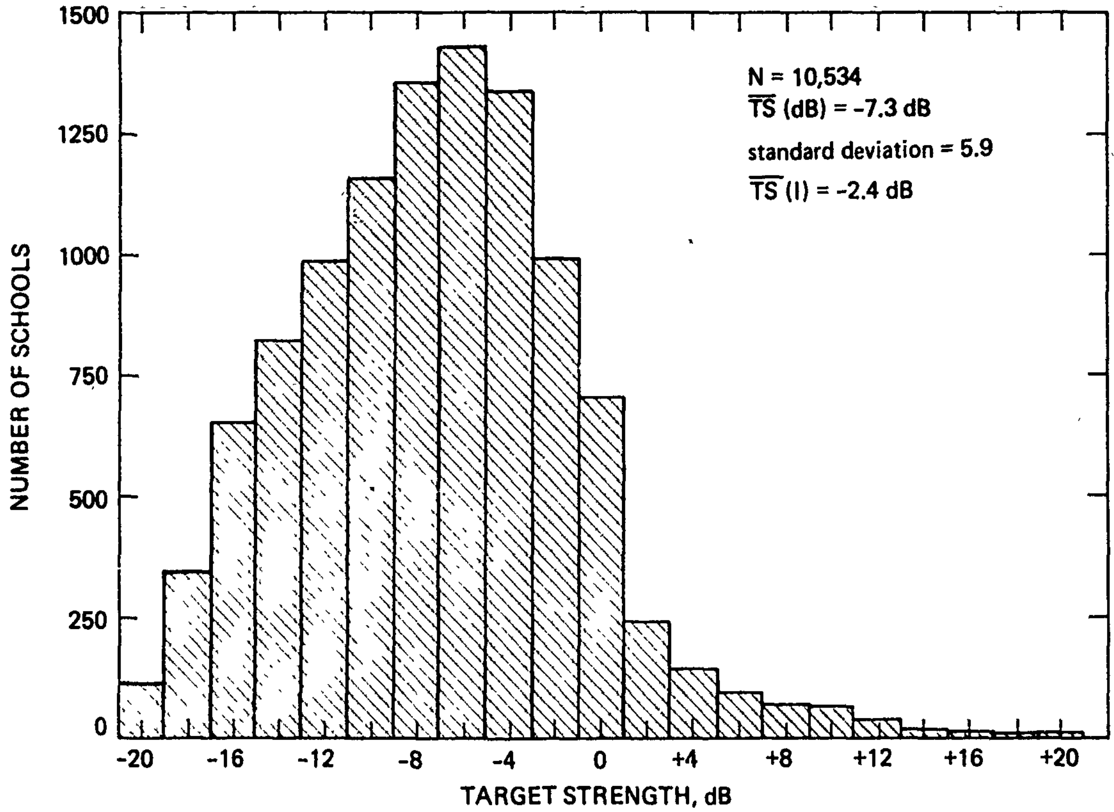
Part E. Cruise 95, 26 June through 20 July 1975.

Figure 7. Continued.



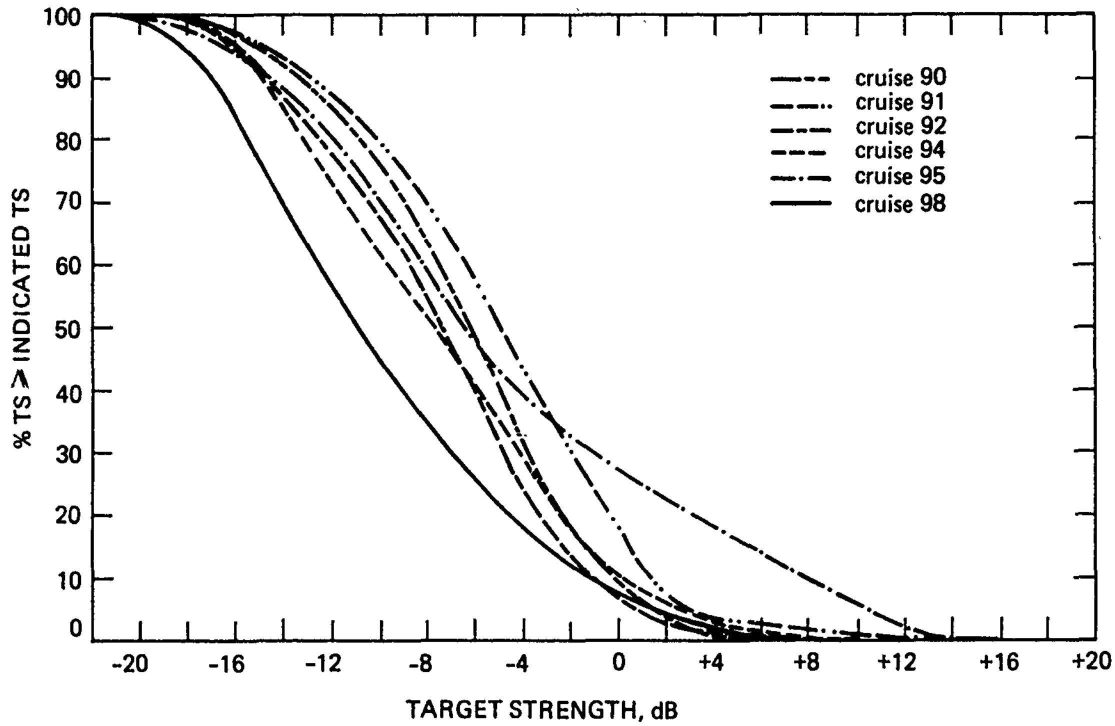
Part F. Cruise 98, 19 October through 29 October 1975.

Figure 7. Continued.



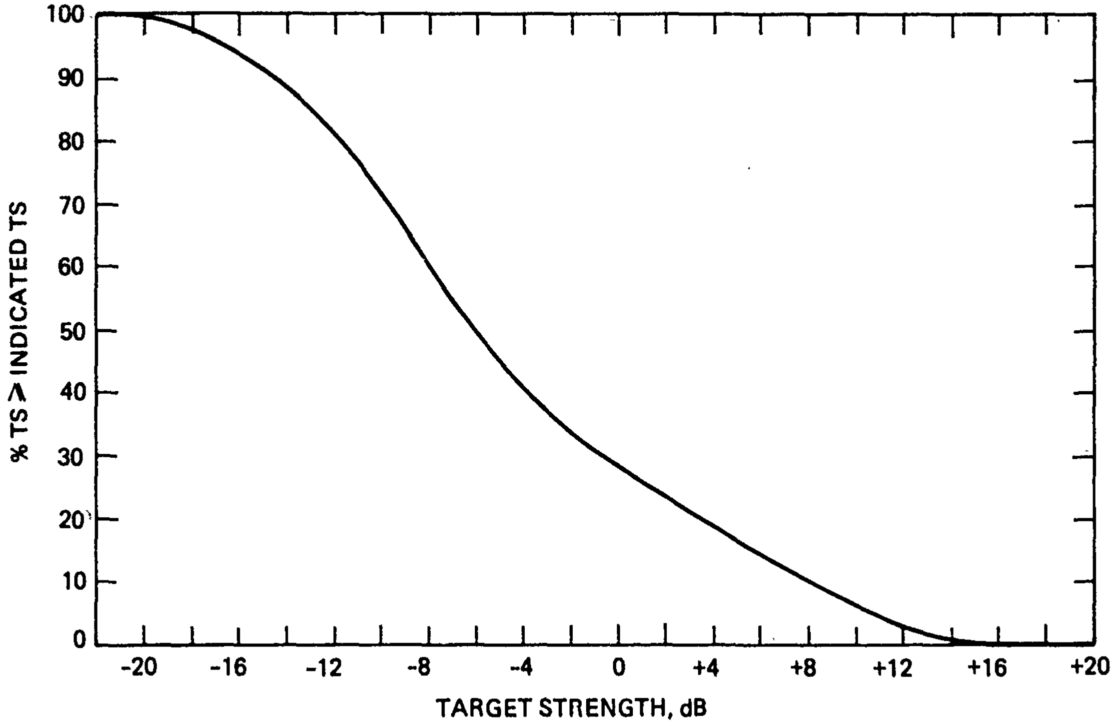
Part G. All cruises.

Figure 7. Continued.



Part A. Individual cruises.

Figure 8. Cumulative distribution of percentage of target strengths greater than or equal to a particular target strength.



Part B. All cruises.

Figure 8. Continued.

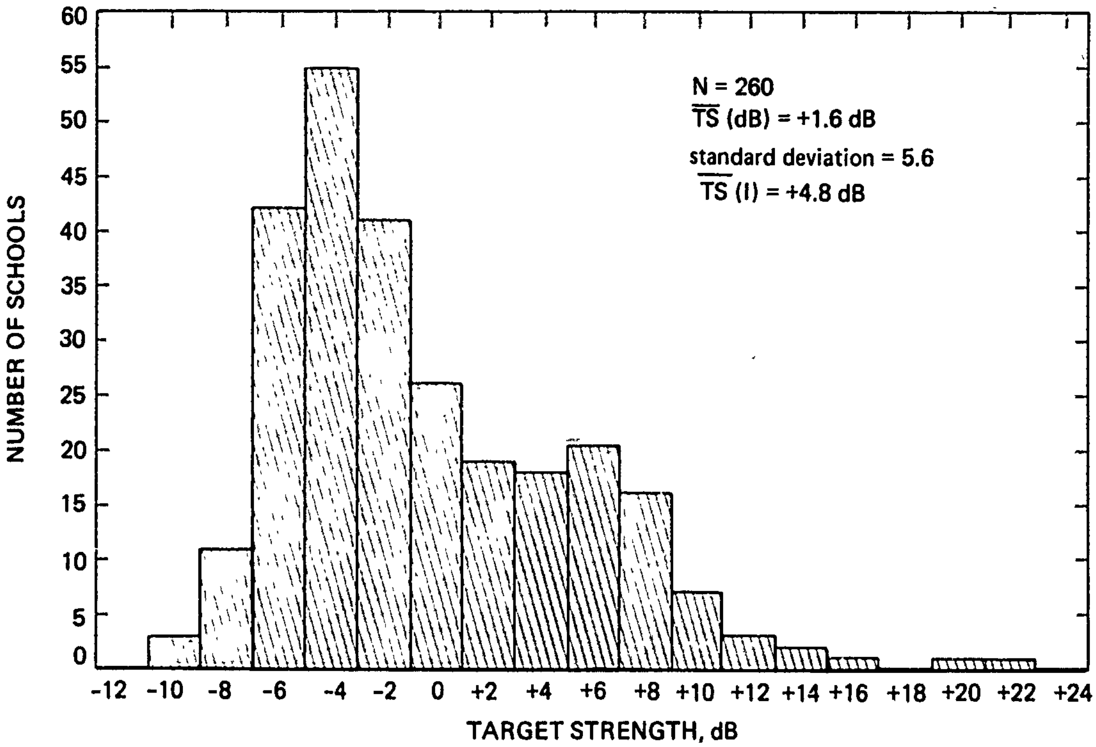


Figure 9. Target strength as a function of frequency of occurrence for long pulse data (170 milliseconds) from cruise 94, 8 May through 4 June 1975.

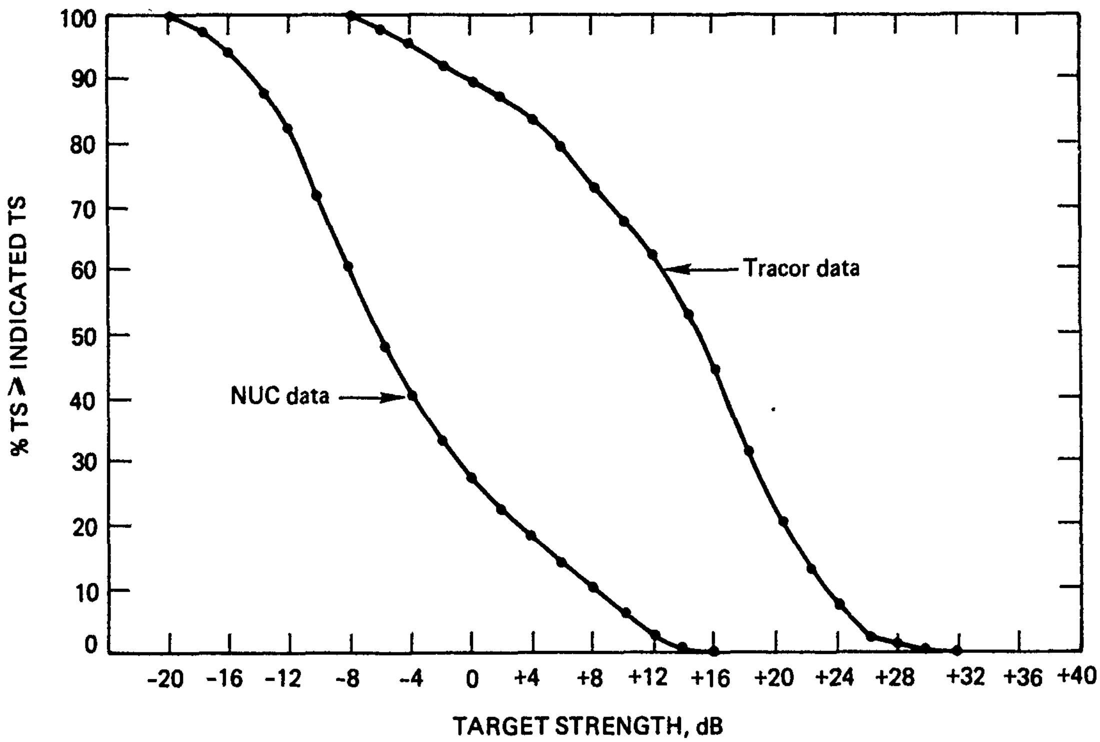


Figure 10. Comparison between NUC and Tracor data sets of fish school target strengths. Curves denote percentage of target strengths greater than or equal to a particular target strength. Both sets were taken from the same vessel at 30 kilohertz, but with different signal processing equipment. The sample size for NUC was 10,534 schools and for Tracor it was 209 schools.

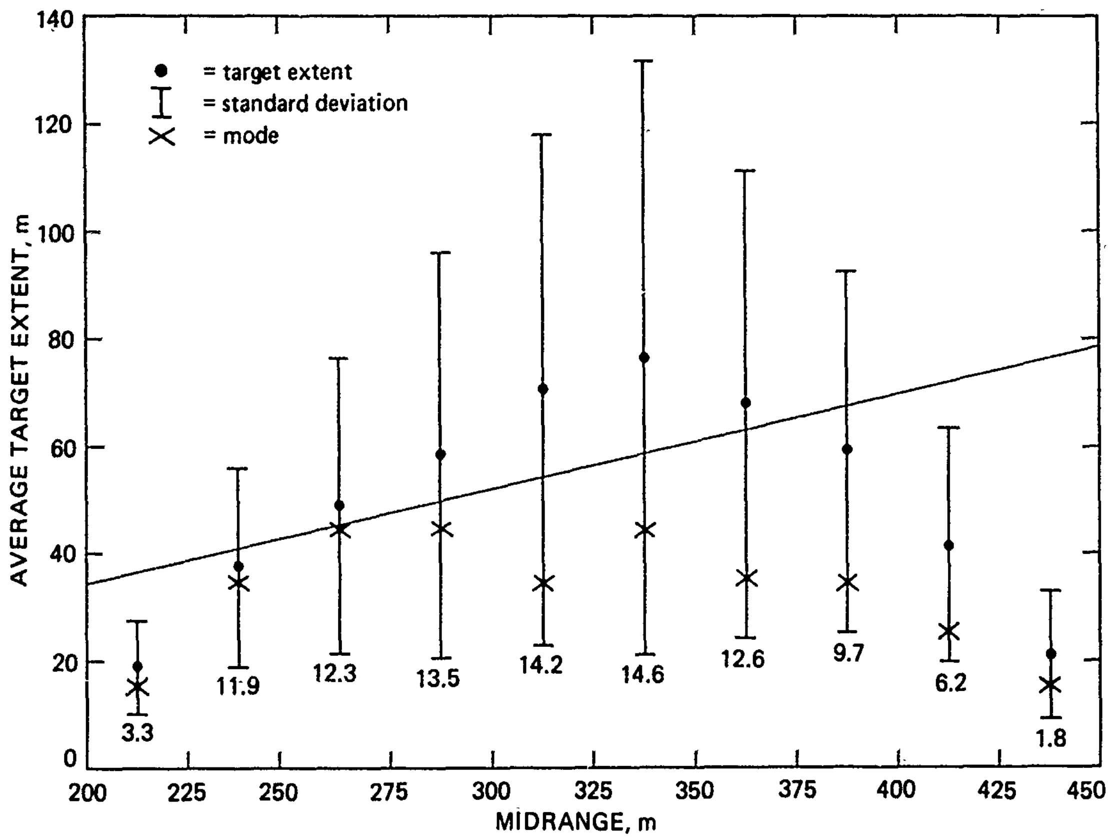


Figure 11. Sampling window, divided into 25-meter increments, as a function of the average target extent of schools whose midrange values are in that increment. The line across the graph is the horizontal beamwidth of the sonar as a function of range. The numbers below the bars are the percentages of total targets inside the range interval.

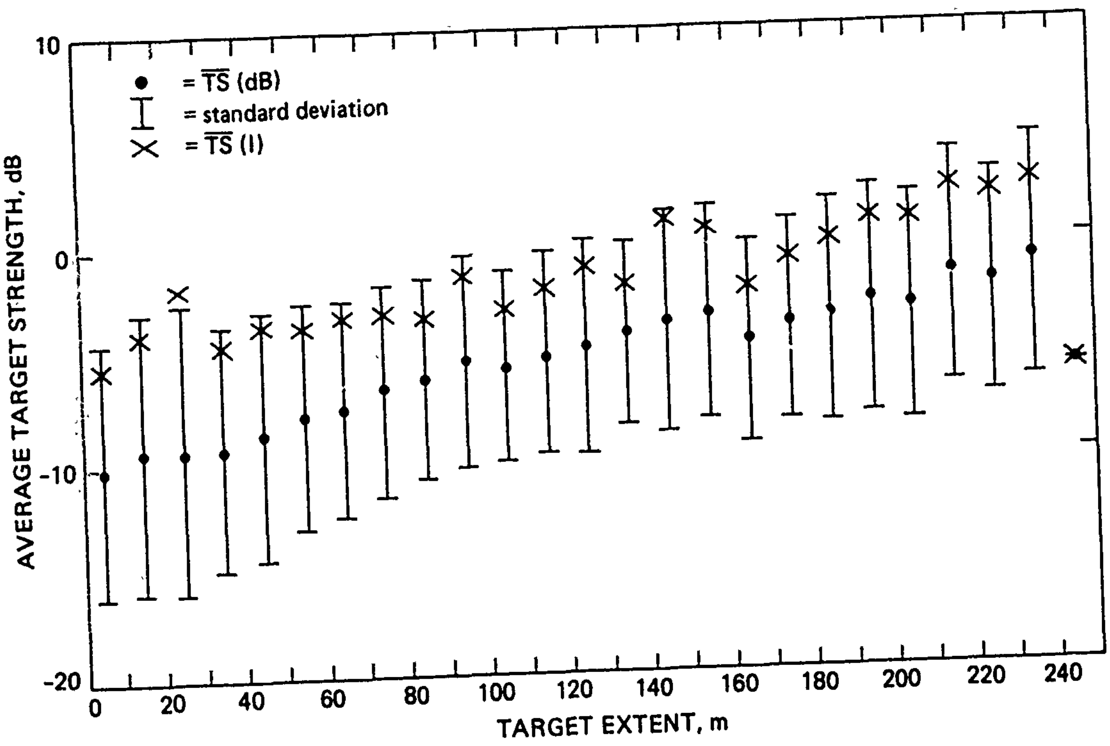


Figure 12. Target extent in 10-meter increments as a function of target strength.

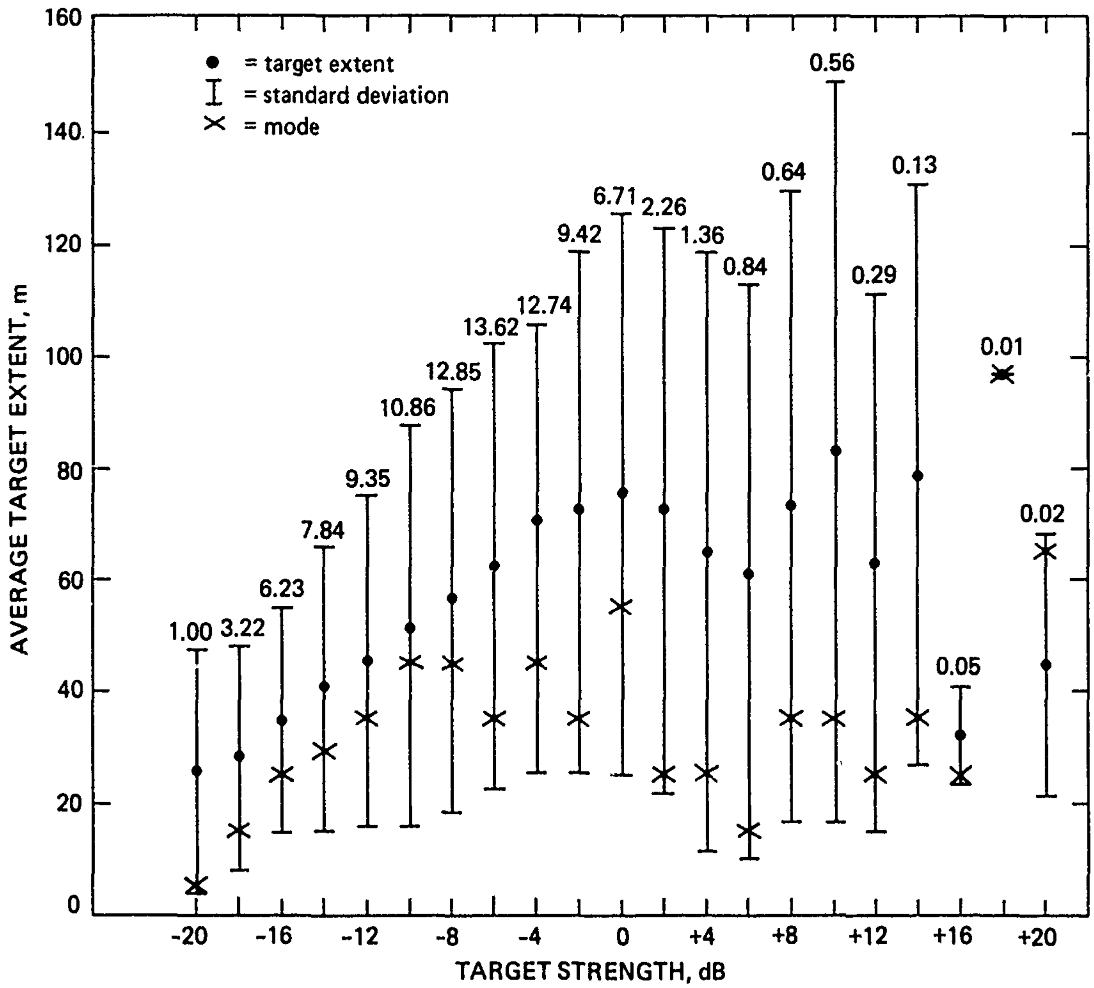


Figure 13. Comparison between target strength and average target extent.